63-1

Final Report

I&R Bit Mix Testing 90

Bituminous

AN EVALUATION OF THE CALDERON TEST

by

Ladis H. Csanyi, Professor

and

Robert L. Gumbert, Research Assistant
Civil Engineering

Project H. R. 80
Iowa Highway Research Board

Project 442-S
July, 1963

IOWA ENGINEERING EXPERIMENT STATION

IOWA STATE UNIVERSITY of Science and Technology / Ames, Iowa

AN EVALUATION OF THE CALDERON TEST

Ladis H. Csanyi, Professor in Charge, Bituminous Research Laboratory
Iowa Engineering Experiment Station, Iowa State University

and

Robert L. Gumbert, Research Assistant, Bituminous Research Laboratory
Iowa Engineering Experiment Station, Iowa State University

INTRODUCTION

A number of tests have been devised to ascertain the physical properties of asphaltic concrete mixes for highway pavements. These tests include the Hubbard-Field Stability Test,[1] the Marshall Stability Test,[2] the Hveem Stabilometer and Cohesiometer Test,[3] and several others.

The Marshall and Hveem tests have been widely accepted primarily because of their simplicity and their correlation with field performance of the mixes. These two tests are empirical in that they group various specific properties of the mix peculiar to the test into overall stability values. They do not yield specific values of properties such as cohesion or internal friction of an asphalt concrete mix. These tests are limited in their results and are valid only for conditions that have been directly correlated with field performance. However, by the use of these tests the design of mixes which can give dependable performance can be developed.

As highway loadings have increased both in weight and traffic volumes some of the asphaltic concrete mixes have failed in performance. Distress has been shown as channelized rutting and shoving. This indicates that design criteria for these methods based on past performance are not always adequate to meet modern traffic conditions. Adjusted criteria have not always been successful. The need has been increasingly evident for a test method which will determine specific values of the physical properties of mixes such as cohesion, internal friction, and perhaps some others such as resistance to displacement.

The Triaxial test method[4] yields such results, but unfortunately its procedure is rather cumbersome and time consuming. Its use has therefore been limited. In 1953 Hector M. Calderon presented a paper before the Association of Asphalt Paving Technologists describing a method that promises to give results similar to those of the Triaxical Test[5, 6]. The Calderon Test is simple and rapid and may be used in laboratory design tests and also in field control tests of asphaltic concrete mixes. Calderon's study indicated good correlation between the results of his test procedure and that of the Triaxial Test.

In 1960 Lincoln M. H. Chang undertook a study in the Bituminous Research Laboratory, as partial fulfillment of requirements for a degree of Master of Science from Iowa State University, to determine if the results of the Calderon Test in relation to a fine graded asphaltic concrete could be correlated with the results from the Marshall and Hveem stability tests[7]. In this study a fine graded asphaltic concrete having a maximum sized aggregate of 1/2 inch was used. The pure shear test mold was slightly modified to overcome a deficiency of the Calderon pure shear mold. Chang obtained rather good correlation of results between the Calderon Test and those of the Marshall and Hveem stability tests.

AUTHORIZATION OF THE PROJECT

As a result of Chang's studies, Calderon's developments, and the need for a new test procedure to determine specific physical properties of an asphalt concrete, the Iowa Highway Research Board sponsored a research project to investigate the correlation of results of the Calderon Test with the Iowa Stability Test and the Marshall and Hveem stability tests using Iowa Type A asphaltic concrete.

The project was assigned to the Bituminous Research Laboratory of Iowa State University as Project HR 80, the Iowa Highway Research Board, and Project 442-S of the Engineering Experiment Station.

PURPOSE AND SCOPE OF THE PROJECT

The purposes of this project are threefold. First, to ascertain how the Calderon test might be used in testing Iowa Type A asphaltic concrete mixes. Second, to determine whether or not the Calderon test may be correlated with the Iowa Stability, the Marshall Stability, or the Hveem Stability tests. Third, to establish, if possible, mix design criteria for the Calderon test in relation to Iowa Type A asphaltic concrete mixes.

The scope of the work under this project includes the test of various mixes by the Calderon, Iowa Stability, Marshall Stability, and Hveem Stability test methods. The mixes so tested were prepared either in the field or in the laboratory. Various combinations and quantities of Ocheydan crushed gravel, sands, and limestone filler or of Garner crushed limestone, sand, and limestone filler were used with 85-100 penetration asphalt cement. All materials were from construction jobs in progress. Also included in these series of tests were mixes prepared in the laboratory under a companion project, "Effect of Fillers", Iowa Highway Research Project HR 79 and Iowa Engineering Experiment Station Project 441-S. The mixes from this project contained Ocheydan crushed gravel, sand, and pulverized loess from Carroll County as the filler with the asphalt cement obtained from the Ocheydan construction job.

THEORY OF THE CALDERON TEST METHOD

In the Calderon test method[5, 6] the results of two separate and distinct tests of the mix, an unconfined compression test, and a pure shear test are used[5, 6]. When the results of these tests are plotted as circles of a Mohr Diagram (figure 1) a straight line tangent to both circles

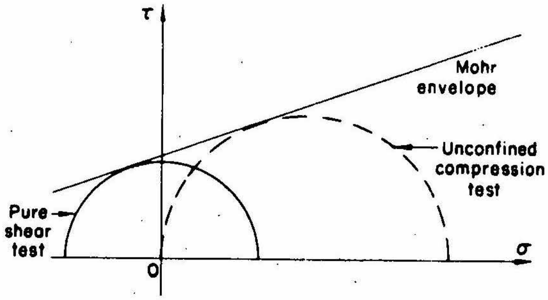


Figure 1

yields the values of unit cohesion (c in psi) and the coefficient of internal friction (angle of internal friction ϕ in degrees) as measured from the diagram. For the unconfined test normal procedures are followed. The pure shear test is novel to the method and is based upon the following analysis[6]:

If a square element a b c d of unit width (figure 2) is subjected to pure shearing stresses as shown, an angular distortion of the element occurs (figure 3). When such stress is applied, a principal unit tensile stress is developed along one diagonal, and a similar compressive stress of equal size develops along the other diagonal. The principal stresses are equal to the unit shear stress which acts on the boundary faces of the element.

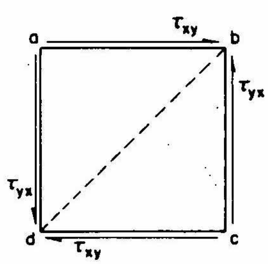


Figure 2

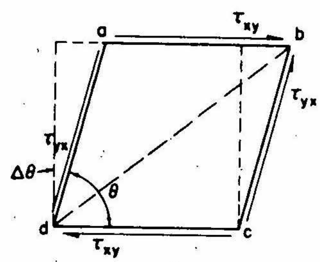


Figure 3

To calculate the unit stress in such a square element it is necessary to compute the transverse area along the horizontal diagonal after distortion, b d e f (figure 4). It is assumed that the total distortion is small, that the boundaries remain straight lines of constant length, and that the volume of the cube will not change appreciably. Whatever its distortion may be, the volume of the specimen can be expressed by the equation:

$$V = DEH = L^2B \tag{1}$$

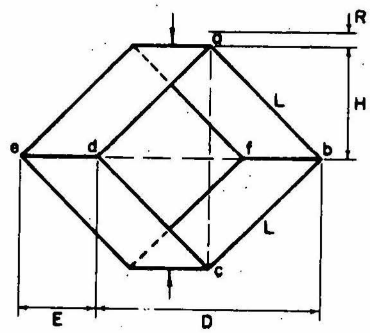


Figure 4

where V = Volume of Specimen
D = Length of diagonal, d b
E = Thickness, c d at any instant
H = One half of diagonal a-c at any instant
L = Length of sides of specimen
B = Initial thickness of specimen
A = Tranverse area b d e f
R = Total vertical strain of specimen

The correct tranverse area of the speciman at any moment during the test is

$$A = DE \tag{2}$$

By substituting equation 2 in equation 1, equation 3 is obtained

$$A = \frac{L^2B}{H} \tag{3}$$

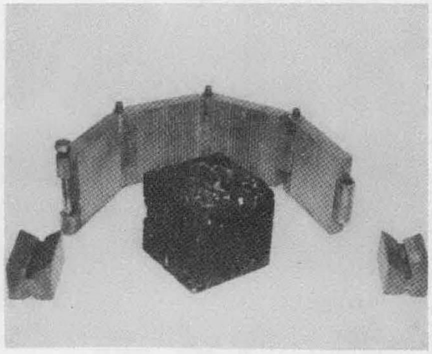
For any given value of R (figure 4) H may be expressed as

$$H = 0.5\,(1.4142L - R) \tag{4}$$

Combining equations 3 and 4, the final equation 5 for the correct tranverse area of the specimen is obtained

$$A = \frac{2L^2B}{1.4142L - R} \tag{5}$$

The apparatus used in the pure shear test is a collapsible box hinged at the corners with the inner surfaces serrated so that the stresses may be transmitted more effectively to the specimen (figure 5). The specimen is placed in the test apparatus and subjected to distortion by applying a compressive force along one of the diagonals (figure 6). From the record of the stress-strain characteristics of the specimen during test up to and beyond the point of failure, a yield point can be identified. The tensile, compressive, or shearing unit stresses at failure or at any other instant may then be calculated from the stress-strain data.



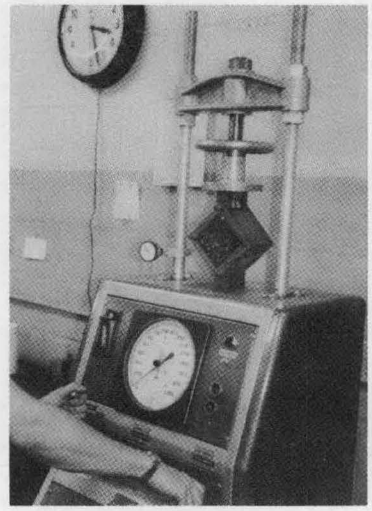


Figure 5, above. Disassembled pure shear testing mold.

Figure 6, at right. Testing a pure shear specimen.

EQUIPMENT AND MATERIALS

APPARATUS

The apparatus used for the Calderon Test by Chang initially for the fine aggregate asphaltic concretes[7] was identical with that used by Calderon[5, 6]. The inner surfaces of Calderon's pure shear test apparatus have rectangular grooves approximately 1/4 inch wide and 1/8 inch deep on approximately 1/2 inch centers, parallel to the hinged joints. The grooves extend from hinge to hinge on each inner face.

In this pure shear test device, stresses between test specimen and inner surfaces of the device could not be adequately transmitted, and excessive slippage occurred. Larger aggregate particles also frequently became wedged in the corners of the device at the hinges and distorted the test results. To overcome these conditions the configuration of the inner surfaces of the device was modified. Saw-tooth wedge-shaped grooves 1/8 inch deep, extending to within one half inch of the hinges corrected the difficulties to some extent. Chang obtained excellent correlations with the modified pure shear test device between the Calderon test results and those of the Marshall and Hveem Stability tests for dense graded fine aggregate asphaltic concretes.

The modified pure shear test device was then used for Iowa Type A, dense graded, 3/4 inch aggregate asphaltic concrete in this study.

SOURCE AND PROPERTIES OF MATERIALS

The materials used in this study were obtained from two asphalt plants producing Iowa Type A asphaltic concrete selected by Iowa State Highway Commission engineers. One plant, located in the vicinity of Ocheydan, Iowa, operated under Contract FN-329 and produced a mix for repaving of a section of Iowa Route 9. The materials were Ocheydan crushed gravel as coarse aggregate, a local sand, and a limestone filler. The other plant located near Garner, Iowa, operated under Contract FN-139 and

Table I. Characteristics of bituminous materials.

Test	Source of material Ocheydan	Garner	Test Method
Penetration 77/100/5	90	89	ASTM D-5
Flash point °F	637	602	ASTM D-92
Softening point °C	50	46	ASTM E-28
Specific gravity 77°F	1.02	1.03	ASTM D-70
Ductility 77°F, cm	150+	150+	ASTM D-113

Table II. Characteristics of aggregates

	Total percent passing						
	Ocheydan			Garner			ASTM
Gradation	3/4"	3/8"	Sand	3/4"	3/8"	Sand	test
3/4"	100.0			100.0			
5/8"	56.5			92.4			
1/2"	55.6			69.8			
3/8"	19.6	100.0		23.0	100.0		
# 4		46.8	100.0	3.3	47.0	100.0	
# 8		5.5	94.7	1.4	3.5	93.0	
# 40			33.5	1.3		51.0	
# 80			15.5			18.5	
# 100			13.4	1.0	2.2	13.2	
# 200	2.7	1.9	8.3	0.7	1.2	5.9	
Apparent specific gravity	2.73	2.70	2.74	2.79	2.78	2.78	C-127
Bulk specific gravity	2.70	2.66	2.71	2.75	2.76	2.74	C-127
Los Angeles abrasion, %	25.16	35.24		25.00	27.00		C-131
Percent voids	40.90	40.80	21.00	40.52	29.57	32.69	C-30
Unit weight, pcf	98.37	95.31	127.60	102.00	104.00	115.00	C-29

Table III. Characteristics of mineral fillers.

Gradation	Ocheydan Dry sieve	Ocheydan Hydrometer	Garner Dry sieve	Garner Hydrometer	Carroll County Loess Dry sieve	Carroll County Loess Hydrometer
	Percent passing					
4	100.0		100.0		100.0	
8	99.5		100.0		99.4	
40	93.0		98.5		69.9	
80	69.9		84.0		53.6	
100	62.6		76.5		50.2	
200	45.4		48.5		46.0	99.0
270		36.0		38.0		98.5
325		32.0		34.0		94.0
400		28.0		29.5		90.0
5 μ		2.0		5.0		37.5
1 μ				2.0		24.5
Apparent specific gravity		2.65		2.74		2.74

produced a mix for surfacing a section of U.S. Highway 69. This plant used Garner crushed limestone as coarse aggregate with local sands and filler. The asphalt cement used in each plant was secured directly from transport trucks.

Since a companion project, also sponsored by the Iowa Highway Research Board, known as "Effect of Fillers on Asphaltic Concrete Mixes" was in progress at the Bituminous Research Laboratory, a series of mixes used in that project containing Ocheydan aggregates with pulverized Carroll County, Iowa, loess was included in this study.

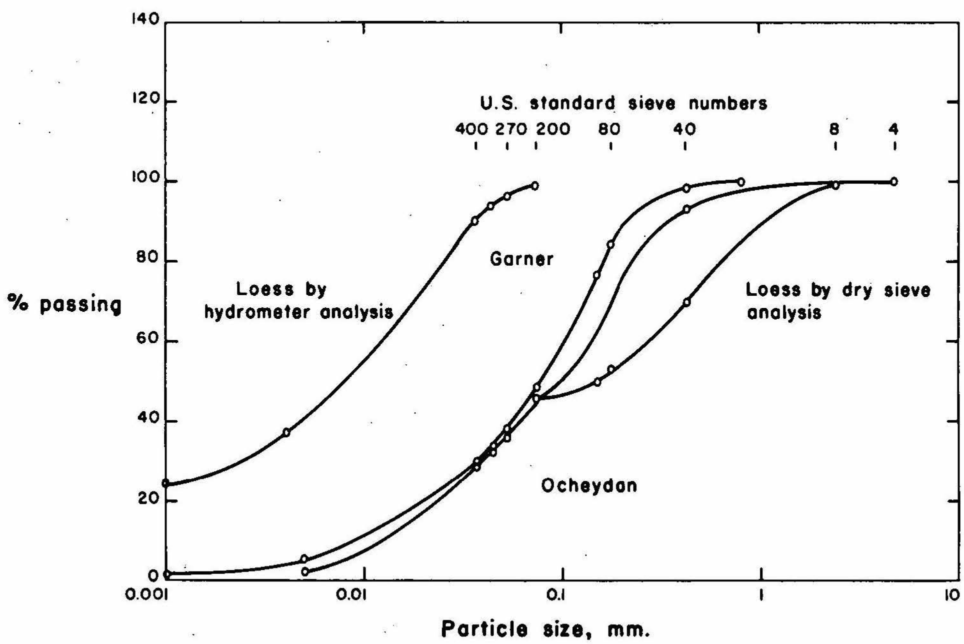


Figure 7

The properties of the asphalt cements used in the mixes are shown in table I. The physical properties of the aggregates used are shown in table II and those of the mineral fillers are shown in table III. The particle size distribution of the fillers are shown in figure 7. All materials were tested in accordance with appropriate A.S.T.M. testing procedures[8, 9] as indicated in the respective tables.

TEST PROCEDURE

The mineral aggregates including the mineral filler, all of which were air dried previously, were blended according to proportions by weight (tables IV and V) to produce a 50 pound batch. The batches were then heated to a temperature of 325°F. The asphalt cement was heated to 300°F in electrically heated laboratory storage tanks.

The mixes were prepared as follows in a fifty pound capacity laboratory twin shaft pug mill mixer having 32 paddle tips:

The heated aggregate blended to proper proportions was placed into the mixer and dry mixed for 20 seconds, the desired quantity of heated asphalt cement (tables IV and V) was then added with a pouring can, and wet mixing was continued for an additional 40 seconds. The total mixing time was about 70 seconds. After being mixed, the asphaltic concrete was discharged from the mixer into pans which were placed on a thermostatically controlled hot plate to keep the temperature of the mix between 250°F and 275°F until test specimens were molded.

The Marshall Stability test specimens were compacted in the prescribed manner with 50 blows of the hammer on each side of the specimen. The Hveem Stability and Iowa State Stability test specimens were compacted under a 3000 psi static load applied by the double plunger method and held for a three minute duration. This method of compaction conforms with Iowa State Highway practice. The Calderon Test specimens were compacted at mix temperatures between 220°F and 250°F. The unconfined compression specimens, cylindrical in shape, 4 inches in diameter and 4 inches high (+ 1/8 inch) were compacted under a static load of 3000 psi by double plunger for one minute. The pure shear test specimens, cubical in shape, 4 inches long, 4 inches wide by 4 inches high (± 1/8 inch) were compacted in a similar manner (figure 8). All test specimens were allowed to air cure at least two days before being tested.

Density and void were determined by a representative sample from each group of test specimens. The Marshall test specimens were tested under standard procedure[2] after immersion in a hot water bath at 140°F for at least 20 minutes. The Hveem test specimens were tested by standard Hveem Stability procedure[3] after being heated in an oven at 140°F for one hour. Other Hveem test specimens were tested by the Iowa State Highway procedure after being immersed in a hot water bath at 140°F for at least 20 minutes. Cohesiometer tests were also conducted at both 140°F dry and 140°F wet conditions.

The Calderon unconfined compression specimens were tested at room temperature, about 75°F, in a compression testing machine under a rate of loading of 0.2 in/min, which is equivalent to 0.05 in/in of specimen height. The load at failure was recorded as the yield point load or maximum load. The Calderon pure shear specimens were also tested at room temperature, about 75°F, in a compression testing machine (figure 6) at a loading rate of 0.02 in/min, which is the same as that used by Calderon but designated as 0.5 mm/min. Load-strain data were recorded at 0.01 inch intervals up to 0.1 inch after which similar data were recorded at 0.05 inch intervals up to the maximum load referred to as the yield point. The yield point load and deformation were used in calculating the shearing strength of the sample. Several tests were duplicated at a loading rate of 0.05 in./min to ascertain the effect of a change in loading rate on the yield point and the Mohr diagram.

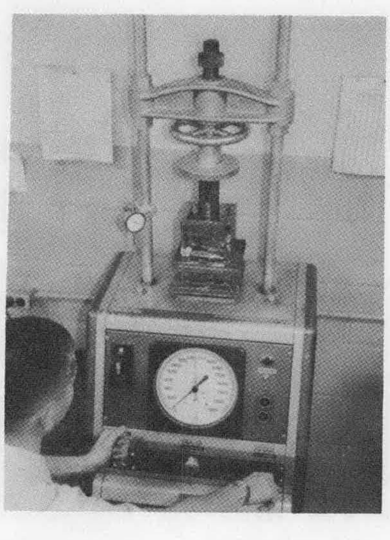


Figure 8. Compacting a pure shear specimen.

Table IV. Proportions of mix constituents using Ocheydan aggregates and respective filler.

%-200 total mix	% aggregate by weight total aggregate 3/4"	3/8"	Sand	Filler[a]	%asphalt total mix
		Lime filler			
0[b]	34.41	23.65	41.94	0.00	4.12
					4.62
					5.10
2 1/2[c]	34.41	23.65	41.94	0.00	4.12
					5.10
					6.06
5	34.04	23.40	41.49	1.07	5.05
					6.00
					6.93
7	32.54	22.37	39.67	5.42	4.84
					5.75
					6.65
10	30.42	20.91	37.07	11.60	6.24
					7.07
					7.88
		Loess filler			
2 1/2	33.44	22.99	40.80	2.77	4.01
					4.97
					6.00
5	32.11	22.08	39.14	6.67	4.99
					6.00
					7.00
7	30.77	21.15	38.02	10.06	5.00
					6.00
					7.00
10	28.95	19.90	35.30	15.85	6.00
					7.00
					8.00

[a] Sufficient filler was added to bring total -200 content, including dust on aggregates, to desired percentage.

[b] Aggregates were washed, then sieved to remove all -200 material.

[c] Aggregates were dry sieved until all but 2.5% of -200 material was removed.

Table V. Proportions of mix constituents using Garner aggregates and filler.

%-200 total mix	% aggregate by weight of total aggregate 3/4"	3/8"	Sand	Filler[a]	% asphalt total mix
		Lime Filler			
0[b]	27.18	25.00	47.82	0.00	4.20
					4.70
					5.10
2 1/2[c]	27.18	25.00	47.82	0.00	4.17
					5.15
					6.12
5	25.80	23.74	45.44	5.02	5.00
					6.00
					7.00
7	24.48	22.52	43.09	9.91	5.00
					6.00
					7.00
10	21.44	19.72	37.74	21.10	5.00
					6.00
					7.00

[a] Sufficient filler was added to bring total -200 content, including dust on agregates, to desired percentage.

[b] Aggregates were washed, then sieved to remove all -200 material.

[c] Aggregates were dry sieved until all but 2.5% of -200 material was removed.

TEST RESULTS

The cohesion and angle of friction of the several mixes was determined by the Calderon Test method (table VI). The results shown are averages of two to four test specimens for the pure shear test and of four specimens for the unconfined compression test. The voids and voids filled with asphalt of the compacted Calderon test specimens were also determined (table VI). The Marshall Stability results and the voids and voids filled with asphalt were determined for the Marshall test specimens of the various mixes (table VII). The results are averages of four tests. The results of the Hveem Stability and the Iowa Stability tests of the various mixes as shown are averages of five tests (table VIII).

Table VI. Calderon Test Results.

Mix		Cohesion psi			Angle of Friction degrees			Percent Voids			% Voids filled with AC		
% Dust	% AC	Ocheydan Loess	Ocheydan Lime	Garner Lime	Ocheydan Loess	Ocheydan Lime	Garner Lime	Ocheydan Loess	Ocheydan Lime	Garner Lime	Ocheydan Loess	Ocheydan Lime	Garner Lime
0.0	4.0	-	110	100	-	49	48	-	8.1	10.1	-	45	45
	4.5	-	88	98	-	47	49	-	8.1	8.3	-	52	52
	5.0	-	86	93	-	43	49	-	7.3	7.3	-	56	56
2.5	4.0	112	138	127	54	47	47	8.8	7.2	7.0	40	52	52
	5.0	76	86	140	52	46	50	6.1	4.9	5.1	53	64	64
	6.0	86	98	130	50	52	52	4.1	1.7	1.2	62	74	83
5.0	5.0	123	108	107	55	46	57	5.3	5.3	4.3	55	62	66
	6.0	85	100	119	53	49	49	3.7	3.3	2.4	65	74	76
	7.0	73	63	80	49	44	50	1.7	1.3	1.2	74	86	86
7.0	5.0	152	193	145	46	46	46	6.9	3.7	5.1	51	63	62
	6.0	172	111	123	52	42	53	4.5	3.3	2.8	61	77	74
	7.0	128	52	110	44	48	45	1.7	1.3	0.8	75	85	87
10.0	5.0	-	138	156	-	47	47	-	3.7	6.7	-	68	57
	6.0	195	48	186	51	56	52	5.7	2.1	4.4	59	79	69
	7.0	147	76	135	47	41	51	2.5	0.8	1.2	70	85	83
	8.0	119	-	-	46	-	-	1.3	0.0	-	77	90	-

Table VII. Marshall Test Results.

Mix		Stability			% Voids			% Voids Filled with AC		
% Dust	% AC	Ocheydan Loess	Ocheydan Lime	Garner Lime	Ocheydan Loess	Ocheydan Lime	Garner Lime	Ocheydan Loess	Ocheydan Lime	Garner Lime
0.0	4.0	-	470	190	-	14.9	12.1	-	35	43
	4.5	-	930	430	-	10.9	11.0	-	47	48
	5.0	-	450	310	-	9.8	10.0	-	53	53
2.5	4.0	488	1720	1050	10.0	7.2	9.4	47	55	49
	5.0	820	1920	1410	8.9	5.2	5.4	56	67	69
	6.0	800	1470	1210	6.9	2.8	3.1	65	82	81
5.0	5.0	1600	940	710	16.1	5.7	7.2	65	66	61
	6.0	1440	970	1230	3.8	4.3	2.6	78	78	84
	7.0	1340	1870	1060	3.1	1.4	1.3	90	95	94
7.0	5.0	1030	1700	1730	11.3	4.7	5.5	49	70	60
	6.0	1310	1490	1370	5.5	3.1	2.9	71	81	82
	7.0	1260	1390	960	3.5	0.3	2.7	93	99	79
10.0	5.0	-	2370	1790	-	3.0	5.8	-	81	65
	6.0	1780	1310	1250	7.2	3.0	5.7	64	84	70
	7.0	1170	1290	1630	5.8	1.7	2.8	72	91	83
	8.0	1480	1050	-	3.1	1.3	-	83	92	-

Table VIII. Test Results.

Mix		Hveem Stability			Iowa Stability		
% Dust	% AC	Ocheydan Loess	Ocheydan Lime	Garner Lime	Ocheydan Loess	Ocheydan Lime	Garner Lime
0.0	4.0	-	34	44	-	27	28
	4.5	-	53	32	-	19	35
	5.0	-	32	43	-	26	32
2.5	4.0	40	38	44	43	39	35
	5.0	40	35	46	41	35	36
	6.0	46	47	51	36	27	27
5.0	5.0	42	40	53	36	38	23
	6.0	41	52	54	26	28	30
	7.0	36	40	51	42	26	49
7.0	5.0	47	44	42	34	32	28
	6.0	62	46	48	25	36	30
	7.0	36	35	37	42	47	55
10.0	5.0	-	46	50	-	24	26
	6.0	52	46	53	23	45	28
	7.0	50	28	52	36	81	23
	8.0	44	-	-	43	140	-

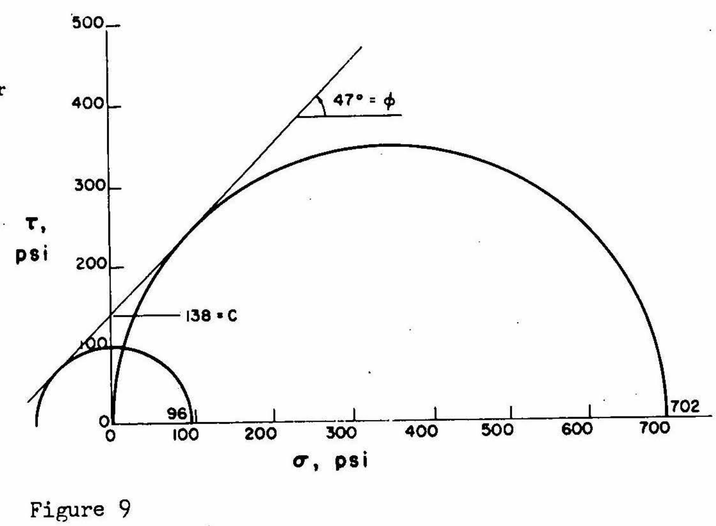


Figure 9

The development of a typical Mohr envelope utilizing the Calderon test results for the Ocheydan aggregate mix containing 10% lime filler and 5% A.C. is shown in figure 9. A typical load-strain diagram for the Ocheydan lime mixes is shown in figure 10.

The Calderon Test results for each mix plotted in a manner used for plotting Smith Triaxial Test results are shown in figures 11 through 15. In these figures mixes found to meet Marshall, Hveem, and Iowa criteria in the respective tests are shown as open symbols, while those failing to meet such criteria are shown in closed symbols.

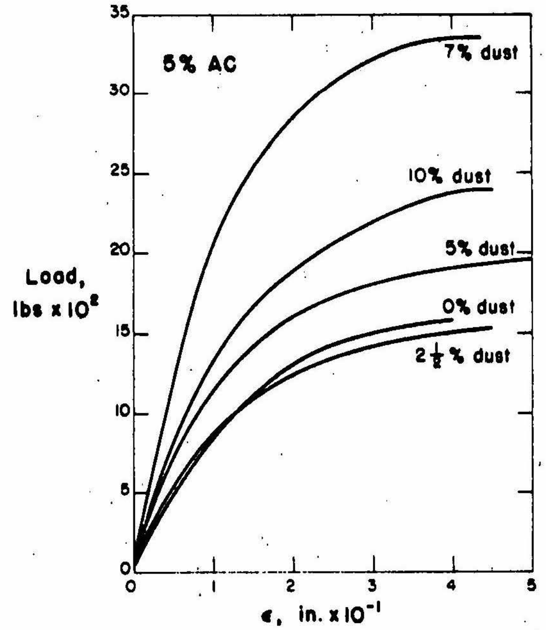


Figure 10. Ocheydan lime, load-strain diagram.

The effects of various asphalt and dust contents in the Ocheydan-lime mixes upon the cohesion and angle of friction as determined by the Calderon Test are shown in figures 16 through 19.

DISCUSSION OF RESULTS

A change in the rate of loading applied in the pure shear and compression tests was found to affect noticeably the resulting Mohr envelope.

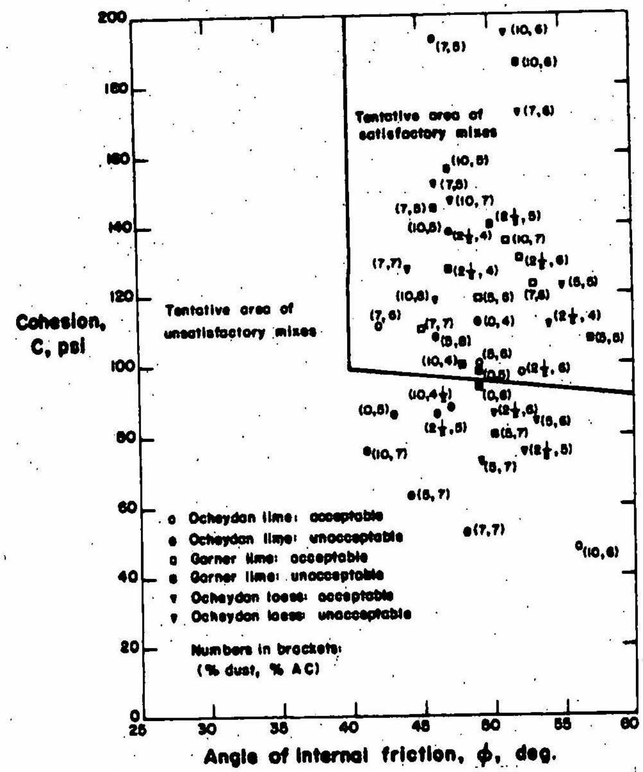


Figure 11. Marshall stability, 500 pound min. criteria.

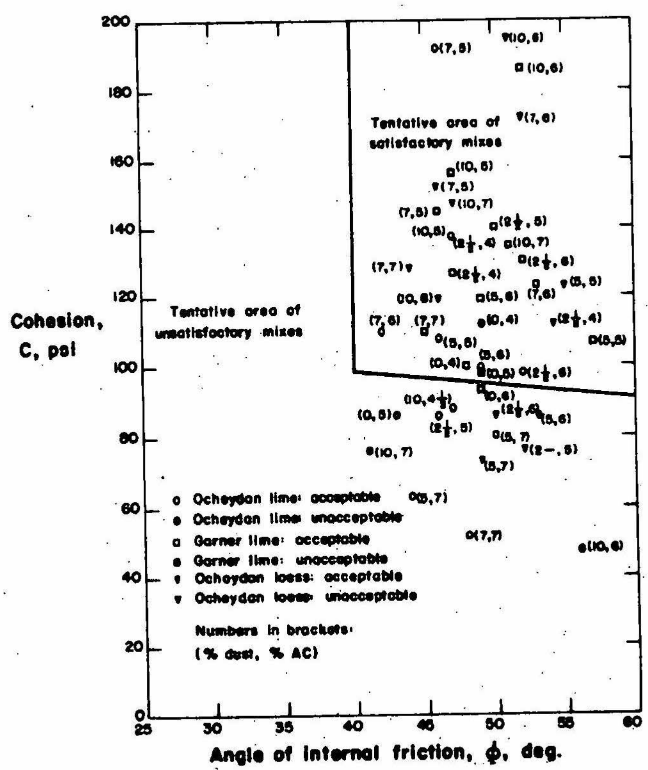


Figure 12. Marshall % voids, 3-5% criteria.

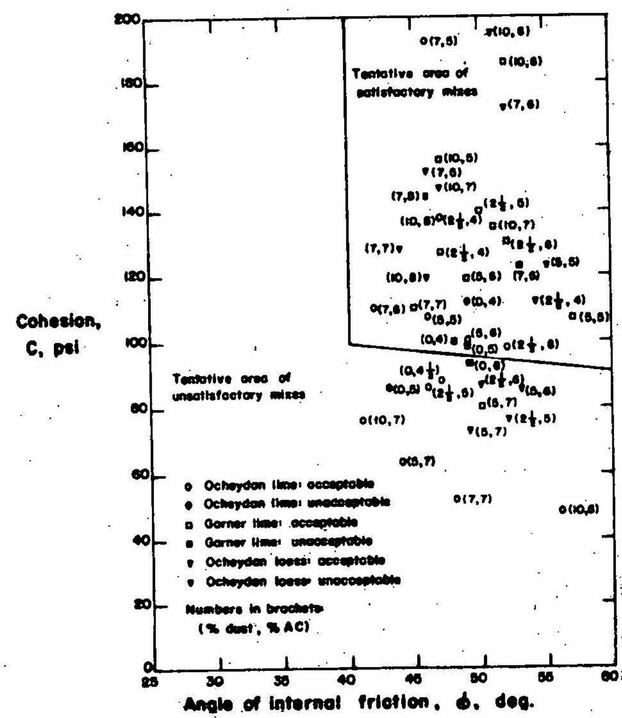


Figure 13. Marshall % voids, filled 75-85% criteria.

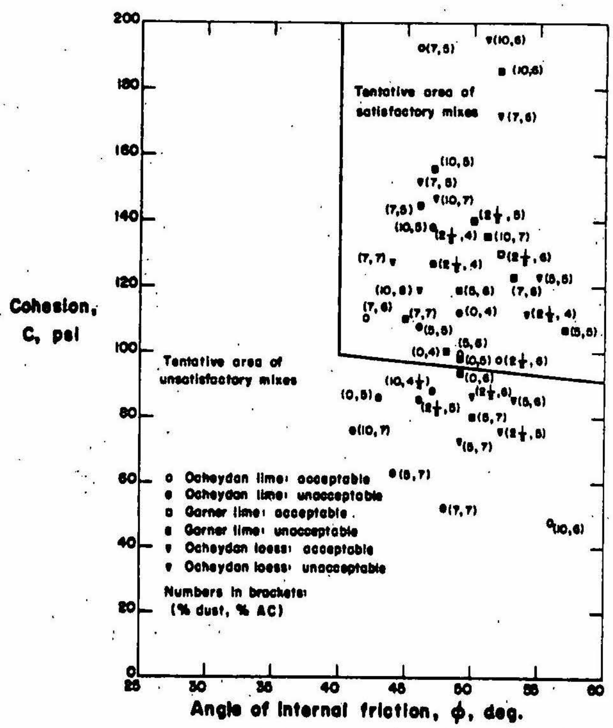


Figure 14. Hveem stability, criteria - 35 min.

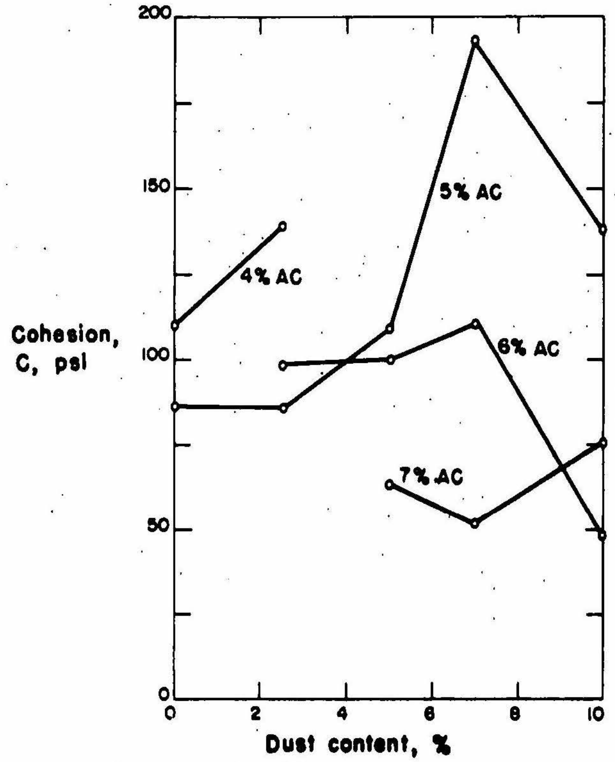


Figure 16. Ocheydan lime.

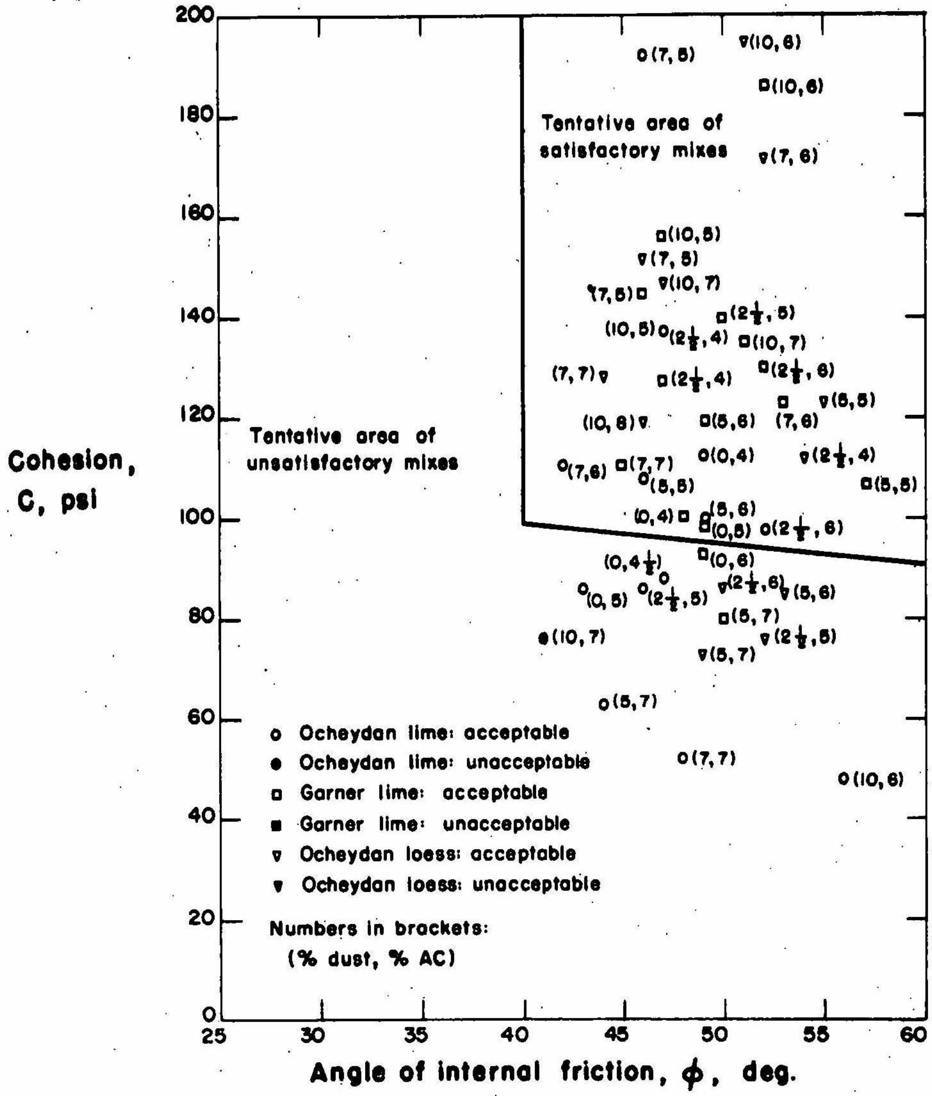


Figure 15. Iowa stability, 60 max. criteria.

In this investigation the rates of loading for the pure shear and compression tests were 0.02 in/min and 0.2 in/min respectively. The 0.02 in/min rate for the shear test is equal to Calderon's rate of 0.5 mm/min; and the 0.2 in/min rate is equal to the standard A.S.T.M. rate of 0.05 in/min/in for a specimen height of four inches in the unconfined compression test. A few tests were conducted to determine the effects of changes in rates of loading. In these tests the rate of loading in the pure shear test was increased two and one half times to 0.05 in/min. The resulting Mohr envelope indicated an increase of about 10% for cohesion and a decrease of a like amount for the angle of friction. The values for cohesion and angle of friction are apparently functions of the rates of loading applied during the test.

In the course of the tests practically all specimens, except those with high filler-high asphalt content mixes, failed in tension rather than shear. This was also observed by Calderon, and he noted that mixes having high internal friction, common throughout this study, failed quite frequently in this manner. He indicates, however, that this condition did not seem to affect his correlation with the triaxial test. It was therefore of minor consequence, other than to indicate that the shearing strength of the mix often slightly exceeds the tensile strength.

The results of the Calderon Test have been plotted in a manner similar to that used by Asphalt Institute[4] with the triaxial test (figures 11 through 15). The boundaries of the Asphalt Institute criteria for suitable mixes which encloses an area having anangle of friction greater than 25° and a cohesion above a sloping line extending from 15 psi at 25° to 7 psi at 45° angle of friction are not shown. Based on these criteria the results of the Calderon Test indicate that all mixes tested would meet the requirements for suitable mixes, and that they are considerably higher than those that would normally be obtained from the triaxial test. The values obtained are as much as five times as great, while those of the angle of friction are as much as 20% larger.

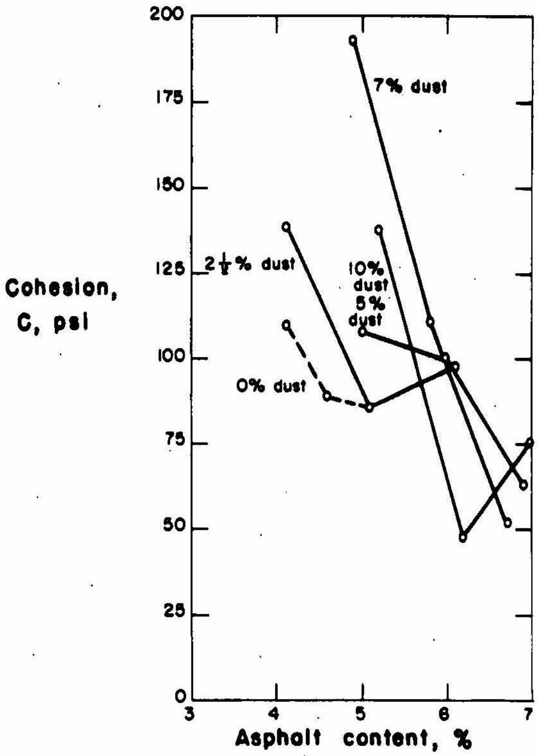


Figure 17. Ocheydan lime.

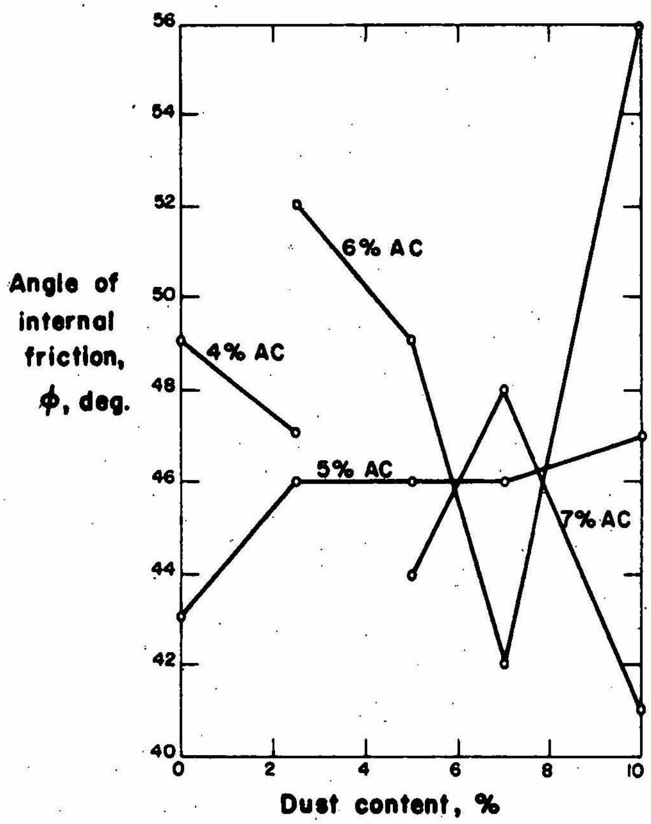


Figure 18. Ocheydan lime.

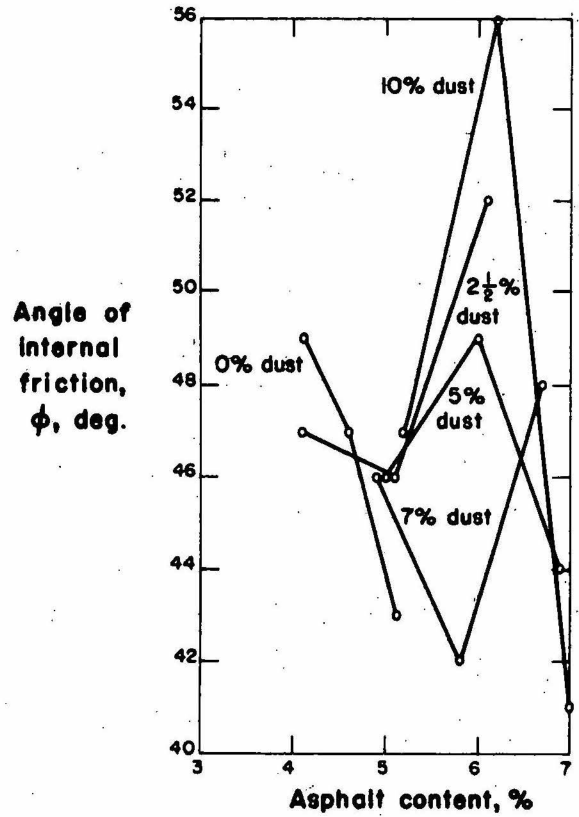


Figure 19. Ocheydan lime.

Calderon found in his original work with fine graded mixes[5] that his results correlated closely with the triaxial test. Chang[7], also using fine graded mixes, however, found high values for test results comparable with those obtained in this study. Chang's results compared favorably with Marshall and Hveem Stability results. Calderon used cut back asphalts in his mixes, and asphalt cements were used both by Chang and in this investigation.

The high values for cohesion noted in this study may, therefore, be attributed to one or more of the following causes: modification of the equipment and procedure, use of asphalt cements in the mixes as compared with cut backs, and the effects of rates of loadings. Since most of the specimens tended to fail in tension in the pure shear test, some further modification of the surface character of the inner faces of the shear test mold may be desirable to attain a more nearly shear effect. The tendency to failure in tension may however be materially reduced and more realistic values of cohesion and angle of friction obtained if the load at a specific deformation, such as 0.1 inch, was used instead of maximum load at failure. The critical effect of rate of loading upon results has already been mentioned. If the rates of loading for the several tests were nearly equalized at a lower level, substantial reduction in cohesion and angle of friction values could be secured.

When the mixes were evaluated on the basis of Marshall, Hveem, and Iowa Stability criteria, most mixes met the requirements of those criteria (figures 11, 14, 15; tables VII, VIII). However, when the mixes were evaluated on the basis of Marshall void and voids filled with asphalt criteria, 3 to 5% voids and 75 to 85% voids filled with asphalt respectively, relatively few of the mixes met the requirements of this criteria (figures 12, 13). No direct relationships could be found between the results of the Calderon test and those of the Marshall, Hveem, and Iowa Stability tests in this investigation similar to those noted by Chang in his study using fine grained aggregate mixes.

In an effort to ascertain whether or not a criteria for satisfactory mix could be established on the basis of the results of the Calderon test secured in this investigation a study was made in adjusting the boundary conditions used in the Asphalt Institute criteria for the triaxial test. Numerous boundary conditions were tried (figures 11 to 15) to adjust for the high cohesion values obtained in this study. Such criteria boundaries could not be established on the basis of comparison with the Marshall, Hveem, and Iowa Stability criteria.

Figure 13 clearly shows that mix containing 7% dust, that portion of the material passing the 200 mesh sieve, will yield the highest cohesion with 5% asphalt cement content. As the asphalt content is increased, cohesion drops. Further, cohesion also is lower with lesser quantities of dust. This may be attributed to the quantity of asphalt present and coating particles. For fixed asphalt content, a mix containing a low quantity of dust will have excess asphalt present and thereby a lower cohesion. As dust content increases to an optimum, cohesion increases. Beyond this the asphalt content becomes insufficient for optimum coating of particles, and cohesion again decreases.

Figures 16 and 18 taken together indicate that as cohesion increases the angle of friction decreases in certain cases. However, in what appears to be the best mix, that using 5% asphalt, the angle of friction remains fairly constant as the cohesion increases up to the maximum.

Although direct correlation of the Calderon Test as applied in this investigation to other methods of test could not be attained, trends in the Calderon Test results do give valuable information. The Calderon Test method seems to be quite sensitive to both the percent of dust and the percent of asphalt contained in the mix (figures 16 - 19).

CONCLUSIONS

1. The theory of the Calderon method is rational and fundamentally sound.

2. The Calderon method may be applied to asphaltic concrete mixes containing aggregates of 3/4 inch maximum size, but further refinement in equipment and procedure is necessary before definite criteria are established.

3. The method indicates dust and asphalt content relationships.

4. Further investigation is necessary to establish optimum loading rates which will yield results for comparison with those of other tests. When this is done criteria for suitable mixes may be reliably predicted.

REFERENCES

1. Mix Design Methods for Asphalt Concrete and other hot mix types. The Asphalt Institute, Manual Series (MS-2) Second Edition, February, 1962, pp. 37-50.
2. Ibid pp. 19-36.
3. Ibid pp. 51-85.
4. Martin & Wallace, Design and Construction of Asphalt Pavements, McGraw Hill, pp. 263-275.
5. Calderon, Hector M. A Possible Approach to Develop a Mohr Diagram. Assoc. of Asphalt Paving Tech. Proc. 22 302-318, 1953.
6. Calderon, Hector M. Prueba De Esfuerzo Cortante Simple, Manual Technico, No. L-2. Laboratorios de la Ingenieria, A. C. Mexico D. F.
7. Chang, Lincoln M. H. Investigation of the Use of the Mohr Diagram for the Design of Bituminous Mixes. M. S. thesis. Library, Iowa State University. 1961.
8. American Society for Testing Materials. A. S. T. M. Standards on Bituminous Materials for Highway Construction, Waterproofing, and Roofing. 8th ed. Phila., Pa. 1960.
9. American Society for Testing Materials. A. S. T. M. Standards on Mineral Aggregates and Concrete. 9th ed. Phila., Pa. 1960.